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Research Article

Effect of Heat Treatment at 200 Degrees on Shore D Hardness Values of Wood Materials of Some Tropical Tree Species

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Abstract: The application of heat treatment leads to various changes in wood properties (mechanical, chemical, physical, biological, surface, etc.). In this study, changes in shore D hardness tests following heat treatment at 200°C for 3 h were determined for wood species including ako (*Antiaris toxicaria*), amarillo (*Centrolobium patinense*), angelim amargosa (*Vataireopsis araroba* (Aguiar) Ducke), onzabili / angongui (*Antrocaryon klaineanum*), bosse (*Guarea cedrata*), burkea (*Burkea africana*), keruing (*Dipterocarpus* spp.), mangga (*Mangifera odorata*), niangon (*Tarrietia utilis*), and rode sali (*Tetragastris altissima*). According to the results, variance analyses were found to be significant. When looking at the rate of decrease obtained, it is observed that for onzabili / angongui it is 16.63%, for ako it is 8.96%, for amarillo it is 10.47%, for bosse it is 26.76%, for angelim amargosa it is 7.00%, for burkea it is 7.11%, for mangga it is 11.33%, for keruing it is 10.03%, for niangon it is 10.53%, and for rode sali it is 13.01%. Decreases in wood species were identified after heat treatment.

Keywords: shore D hardness; heat treatment; wood material

Bazı Tropikal Ağaç Türlerine Ait Ahşap malzemelerde Shore D Sertlik Değerleri üzerine 200 Derecede Isıl İşlemin Etkisi

Öz: Isıl işlem uygulaması ile ahşap malzemenin sahip olduğu birçok özellik (mekanik, kimyasal, fiziksel, biyolojik, yüzey, vb.) değişmektedir. Bu çalışmada, ako (*Antiaris toxicaria*), amarillo (*Centrolobium patinense*), angelim amargosa (*Vataireopsis araroba* (Aguiar) Ducke), onzabili / angongui (*Antrocaryon klaineanum*), bosse (*Guarea cedrata*), burkea (*Burkea africana*), keruing (*Dipterocarpus* spp.), mangga (*Mangifera odorata*), niangon (*Tarrietia utilis*) ve rode sali (*Tetragastris altissima*) ağaç türlerine ait odunların 200 °C'de 3 saat süre ile ısıl işlem görmesinden sonra meydana gelen shore D testine ait değişiklikler belirlenmiştir. Sonuçlara göre, varyans analizleri anlamlı olarak belirlenmiştir. Elde edilen bu azalma oranlarına bakıldığında; onzabili / angongui için %16.63, ako için %8.96, amarillo için %10.47, bosse için %26.76, angelim amargosa için %7.00, burkea için %7.11, mangga için %11.33, keruing için %10.03, niangon için %10.53 ve rode sali için %13.01 olarak bulunduğu görülmektedir. Isıl işlem sonrası ağaç türlerinde azalmalar tespit edilmiştir.

Anahtar Kelimeler: shore D sertlik; ısıl işlem; ahşap malzeme

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1. Introduction

Wood is an intricate substance fundamentally comprised of three biopolymers: lignin, cellulose, and hemicellulose. In addition to these polymeric components, the wood may contain a greater or lesser amount of extractives, which may include various organic compounds such as sugars, flavonoids, tannins, terpenes, oils, or waxes [1].

Wood is a sustainable resource with a wide range of applications due to its physical, mechanical, and anatomical properties. It finds use in diverse fields, including construction, furniture manufacturing, pulp and paper production, and even serves as a significant source for energy production. In comparison to materials like concrete, plastic, steel, and aluminum, wood boasts numerous advantages, such as its appealing aesthetics, impressive mechanical strength, ease of working with, and excellent thermal insulation properties. However, it's worth noting that wood also has some limitations, including its relatively lower natural durability and susceptibility to issues like cracking and warping [2].

Wood offers a multitude of technical benefits for a diverse array of uses, thanks to its elevated specific resistance, impressive hardness, substantial rigidity, minimal energy requirements for processing, regenerative nature, and aesthetic appeal [3].

Hardness is the ability to withstand the force of a harder object trying to penetrate or bond with it. Hardness testing is generally a straightforward, quick, and effective method, often considered a nearly non-destructive test. Various hardness testing techniques primarily vary in terms of the shape and material of the indenter, the magnitude and duration of the applied force, and the way the force is applied (either during the entire test or after the force is removed)[4].

Hardness is the capacity of a material to resist deformation, especially when it comes to permanent deformation, indentation, or scratching. It's crucial to note that hardness is a relative term and should not be confused with the wear and abrasion resistance found in plastic materials. Various testing methods have been developed to evaluate hardness. The Durometer hardness testing device consists of a pressure foot, an indenter, and an indicator mechanism. The indenter is spring-loaded, with its tip protruding from a hole in the base. The testing procedure begins by placing a sample on a firm, level surface while ensuring that the pressure foot of the device is parallel to the sample's surface. The Durometer hardness value is determined within one second of the pressure foot making solid contact with the sample's surface [5].

The durometer scale consists of a calibrated spring that exerts a certain pressure on a recessed foot, which can be cone- or sphere-shaped [6].

Shore hardness is a measure of the material's resistance to bonding by a 3 spring indenter. The higher the number, the greater the resistance [7]. The Shore durometer is primarily employed for assessing the indentation hardness of materials like rubbers, thermoplastic elastomers, and pliable plastics, including polyolefins, fluoropolymers, and vinyl [8].

Subjecting wood to heat treatment at temperatures exceeding 150°C has an impact on both its physical and chemical characteristics. Beyond 200°C, the alterations in wood become substantial, including a decrease in dimensional changes like shrinkage and swelling, enhanced resistance to decay, a darker coloration, loss of extractive substances, lower equilibrium moisture content, and an improved thermal insulation capability [9]. Loss of extractives can cause both color and surface chemistry changes in wood flour. It has been reported in the literature that between 100 and 200°C, wood releases traces of water, carbon oxides, and organic decomposition products [12], [13].

Elevated temperatures causing the degradation of wood can result in undesirable characteristics, including the development of unpleasant odors, changes in color, and a reduction in mechanical strength [10].

Thermal treatment is recognized as an efficient technique for altering wood properties. It lowers the wood's hygroscopic nature, leading to improved dimensional stability and, depending on moisture content, indirectly reinforcing mechanical characteristics. Moreover, thermal treatment plays a vital role in preserving the shape of compressed and curved wood products [11].

In most cases, the properties of wood are related to the chemistry of the cell wall and change by changing the chemistry of the cell wall polymers [14]. The main disadvantage of wood heat treatment is that most mechanical properties (mainly impact strength, hardness and stiffness) deteriorate. On the contrary, some mechanical properties (mainly modulus of elasticity) can be improved by heat treatment [15].

In this study, shore D hardness values of ako, amarillo, angelim amargosa, onzabili / angongui, bosse, burkea, keruing, mangga, niangon and rode sali wood species heat treated at 200°C for 3 hours were investigated. These tree species are among the significant tree types evaluated in various fields abroad. In the literature, it is observed that shore D hardness values for these types of wood after heat treatment have not been conducted.

2. Experimental

In this study, wood from ako (*Antiaris toxicaria*), amarillo (*Centrolobium patinense*), angelim amargosa (*Vataireopsis araroba* (Aguiar) Ducke), onzabili / angongui (*Antrocaryon klaineanum*), bosse (*Guarea cedrata*), burkea (*Burkea africana*), keruing (*Dipterocarpus* spp.), mangga (*Mangifera odorata*), niangon (*Tarrietia utilis*) and rode sali (*Tetragastris altissima*) were used.

The test material was purchased from a commercial enterprise as 100 x 100 x 20 mm of 1st class quality. The test samples were carefully selected to be free of cracks, with smooth and uninterrupted fibers, without knots or defects, and with consistent color and density. The samples were then prepared according to TS ISO 13061-1, (2021) standard [16].

In the study, wood samples from selected foreign tree species were subjected to a heat treatment process in a thermal treatment oven at 200°C for a duration of 3 h.

Shore D hardness values were determined by taking 10 measurements on a shore meter with a load of 5 kg according to ASTM D 2240 (2010) [17].

Table 1. Some important information about the Shore D hardness test [18].

Indentation Depth / Test Force	Indentation Geometry / Material
0 mm≤ h≤ 2.5 mm	Truncated cone
0 N≤ F≤ 44.5 N	Spherical clamshell
	R= 0.1 mm
	R_0 =1.25 mm

Figure 1. View of the Shore D tester.

Means, maximum measurement values, minimum measurement values, homogeneity groups, standard deviations, multivariate analysis of variance and percentage (%) change rates were calculated with a statistical program.

3. Results and Discussion

Table 2 shows the results of the analysis of variance for the shore D hardness values determined in various wood species. When the results obtained are examined, it is seen that the wood species (A) factor, heat treatment (B) factor and the interaction (AB) value obtained by the factors are determined to be significant for shore D hardness.

Table 2. Results of variance analysis.

Variance Source	Sum of Squares	Degrees of Freedom	Mean Square	F Value	α ≤ 0.05
Wood species (A)	17969.705	9	1996.634	560.765	0.000*
Heat treatment (B)	2895.605	1	2895.605	813.245	0.000*
Interaction (AB)	835.145	9	92.794	26.062	0.000*
Error	640.900	180	3.561		
Total	698277.000	200			
Corrected total	22341.355	199			

* Significant.

The results of the shore D hardness values and densities determined in various wood species are presented in Table 3. Decreases in shore D hardness values were detected in wood species after heat treatment. These decreases were 8.96% for ako, 10.47% for amarillo, 7.00% for angelim amargosa, 16.63% for onzabili, 26.76% for bosse, 7.11% for burkea, 10.03% for keruing, 11.33% for mangga, 10.53% for niangon and 13.01% for rode sali (Table 3).

When the studies in the literature on the shore D test determined after heat treatment are examined, it is reported that decreases were obtained [19]–[26]. The results obtained in the study were consistent with the studies conducted in the literature.

According to explanations in the literature regarding the decline in hardness after heat treatment, it has been expressed as follows [27]: The main reason for the loss of strength is the breakdown of hemicellulose, which is less resistant to heat compared to cellulose and lignin. It is a widely acknowledged fact that alterations in hemicellulose contribute significantly to the strength properties of wood heated at elevated temperatures [28].

Table 3. Results of shore D hardness values.

Wood Type	Treatment Type	Mean (HD)	Change Rate (%)	Homogenity Group	Coefficient of Variation	Minimum	Maximum	Standard Deviation
Ako	Non-heat-treated	46.90	↓ 8.96	K	7.14	43.00	51.00	3.35
(*Antiaris toxicaria*)	Heat-treated	42.70		M	6.05	40.00	48.00	2.58
Amarillo	Non-heat-treated	72.60	↓ 10.47	B	3.51	69.00	75.00	2.55
(*Centrolobium patinense*)	Heat-treated	65.00		D	1.26	64.00	66.00	0.82
Angelim amargosa	Non-heat-treated	55.70	↓ 7.00	G	0.87	55.00	56.00	0.48
(*Vataireopsis araroba*)	Heat-treated	51.80		H	2.99	50.00	53.00	1.55
Onzabili / Angongui	Non-heat-treated	45.10	↓ 16.63	L	5.77	42.00	49.00	2.60
(*Antrocaryon klaineanum*)	Heat-treated	37.60		N**	7.22	34.00	40.00	2.72
Bosse	Non-heat-treated	71.00	↓ 26.76	BC	1.88	70.00	73.00	1.33
(*Guarea cedrata*)	Heat-treated	52.00		J	2.40	49.00	53.00	1.25
Burkea	Non-heat-treated	75.90	↓ 7.11	A*	1.58	75.00	78.00	1.20
(*Burkea africana*)	Heat-treated	70.50		C	3.68	66.00	73.00	2.59
Keruing	Non-heat-treated	59.80	↓ 10.03	F	2.82	56.00	61.00	1.69
(*Dipterocarpus* spp.)	Heat-treated	53.80		H	3.37	51.00	56.00	1.81
Mangga	Non-heat-treated	60.00	↓ 11.33	EF	1.57	59.00	61.00	0.94
(*Mangifera odorata*)	Heat-treated	53.20		IJ	1.19	52.00	54.00	0.63
Nangon	Non-heat-treated	61.70	↓ 10.53	E	2.03	60.00	63.00	1.25
(*Tarrietia utilis*)	Heat-treated	55.20		GH	3.80	53.00	59.00	2.10
Rode sali	Non-heat-treated	70.70	↓ 13.01	C	2.31	69.00	73.00	1.64
(*Tetragastris altissima*)	Heat-treated	61.50		EF	2.20	60.00	63.00	1.35

* Highest result, ** Lowest result

4. Conclusions

In the study, it was observed that the results of multivariate analysis of variance were obtained significantly with heat treatment. The shore D values of all wood species decreased with 3 hours of heat treatment at 200 degrees. The highest rate of reduction was observed in bosse wood, while the lowest was identified in Angelim amargosa wood. Different reduction results were obtained due to the different structures of wood materials (anatomical, chemical, physical, etc.).

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References

[1]. G. N. Inari, M. Petrissans, J. Lambert, J. J. Ehrhardt, and P. Gerardin, "XPS characterization of wood chemical composition after heat-treatment. Surface and Interface Analysis," An International Journal devoted to the development and application of techniques for the analysis of surfaces, interfaces and thin films, vol. 38, no. 10, pp. 1336–1342, 2006.
[2]. J. M. Vidal, W. V. Evangelista, J. de Castro Silva, and I. P. Jankowsky, "Wood preservation in Brasil: historical, current scenario and trends," Ciência Florestal, Santa Maria, vol. 25, no. 1, pp. 257–271, 2015.
[3]. B. Stefke, E. Windeisen, M. Schwanninger, and B. Hinterstoisser, "Determination of the weight percentage gain and of the Acetyl group content of Acetylated wood by means of different infrared spectroscopic methods," Anal Chem, vol. 80, no. 4, pp. 1272–1279, 2008.
[4]. T. Koch, C. Bierögel, and S. Seidler, "Conventional Hardness Values-Introduction: Polymer Solids and Polymer Melts," Polymer Solids and Polymer Melts-Mechanical and Thermomechanical Properties of Polymers, pp. 423–427, 2014.
[5]. M. Kutz, Handbook of materials selection. John Wiley & Sons, 2002.
[6]. A. Shore, "Apparatus for Measuring the Hardness of Materials," 1770045, Jun. 08, 1930
[7]. A. Alavudeen, N. Venkateshwaran, and J. W. Jappes, A textbook of engineering materials and metallurgy. Firewall Media, 2006.
[8]. L. Coltro, J. B. Pitta, and E. Madaleno, "Performance evaluation of new plasticizers for stretch PVC films," Polym Test, vol. 32, no. 2, pp. 272–278, Apr. 2013, doi: 10.1016/j.polymertesting.2012.11.009.
[9]. P. Viitaniemi and S. Jämsä, "Modification of wood with heat treatment," Finland, 1994.
[10]. A. J. Nunez, J. M. Kenny, M. M. Reboredo, M. I. Aranguren, and N. E. Marcovich, "Thermal and dynamic mechanical characterization of polypropylene-wood flour composites," Polym Eng Sci, vol. 42, no. 4, pp. 733–742, 2002.
[11]. D. Sandberg, P. Haller, and P. Navi, "Thermo-hydro and thermo-hydro-mechanical wood processing: An opportunity for future environmentally friendly wood products," Wood Mater Sci Eng, vol. 8, no. 1, pp. 64–88, Mar. 2013, doi: 10.1080/17480272.2012.751935.
[12]. F. Shafizadeh, "Pyrolytic reactions and products of biomass," in Fundamentals of thermochemical biomass conversion, New York: Elsevier, 1985, pp. 183–217.
[13]. S. L. LeVan, In Concise Encyclopedia of Wood and Wood-Based Materials. Scniewind, 1989.
[14]. R. M. Rowell, "Chemical Modification of Wood," in Handbook of Engineering Biopolymers: Homopolymers, Blends and Composites, Cincinnati: Hanser Gardner Publications, 2007, pp. 673–691.
[15]. L. Reinprecht and Z. Vidholdová, Thermowood. Ostrava: Šmíra-print, 2011.
[16]. TS ISO 13061-1, (2021). Odunun fiziksel ve mekanik özellikleri - Kusursuz küçük ahşap numunelerin deney yöntemleri - Bölüm 1: Fiziksel ve mekanik deneyler için nem muhtevasının belirlenmesi, Türk Standartları Enstitüsü, Ankara, Türkiye
[17]. ASTM D 2240, (2010). Standard test method for rubber property-durometer hardness, American Society for Testing and Materials, West Conshohocken, Pennsylvania, United States
[18]. W. Grellmann and S. Seidler, "Part 3: Mechanical and Thermomechanical Properties of Polymers," in Polymer Solids and Polymer Melts, vol. Subvolume A, Berlin: Springer-Verlag, 2014.
[19]. Ü. Ayata, "Sibirya'da iç ve dış mekânlarda kullanılan Sibirya çamı odununun yüzey pürüzlülüğü parametreleri ve shore D sertlik değeri üzerine ısıl işlemin etkisi," Mobilya ve Ahşap Malzeme Araştırmaları Dergisi, vol. 4, no. 1, pp. 1–8, Jun. 2021, doi: 10.33725/mamad.911611.
[20]. Ü. Ayata, "Palo Santo odununda bazı yüzey özellikleri ve shore D sertlik değeri üzerine 2000C'de ısıl işlemin etkisi," Mobilya ve Ahşap Malzeme Araştırmaları Dergisi, vol. 6, no. 1, pp. 39–46, Jun. 2023, doi: 10.33725/mamad.1280180.
[21]. Ü. Ayata and B. C. Bal, "Kopie, fukadi ve porsuk ağaç türlerinde renk, parlaklık ve shore D sertlik üzerine ısıl işlemin etkisi," in Hoca Ahmet Yesevi, 5. Uluslararası Bilimsel Araştırmalar Kongresi, Nahçıvan , 2021, pp. 166–180.
[22]. Ü. Ayata and B. C. Bal, "2000C'de ısıl işlem görmüş kırmızı karaağaç (Ulmus rubra) odununda bazı yüzey özelliklerinin ve shore D sertlik değerinin araştırılması," in 5. Asya Pasifik Uluslararası Modern Bilimler Kongresi , Sydney, 2021, pp. 258–270.
[23]. B. Esteves, S. Sahin, Ü. Ayata, I. Domingos, J. Ferreira, and L. Gürleyen, "Effect of heat treatment on shore-D hardness of some wood species," Bioresources, vol. 16, no. 1, pp. 1482–1495, Jan. 2021, doi: 10.15376/biores.16.1.1482-1495.
[24]. M. Türk and Ü. Ayata, "Türkiye'de yetişen bazı ağaç türlerine ait odunlarda shore D sertlik değerleri üzerine ısıl işlemin etkisi," Mobilya ve Ahşap Malzeme Araştırmaları Dergisi, vol. 4, no. 2, pp. 166–173, Dec. 2021, doi: 10.33725/mamad.1005127.
[25]. M. Türk and Ü. Ayata, "200^{0}C'de ısıl işlem görmüş mor kalp ağacı odununda shore D sertlik değerinin ve yüzey pürüzlülüğü parametrelerinin incelenmesi," Eurasian Journal of Forest Science, vol. 9, no. 3, pp. 134–142, 2021.
[26]. G. Ulay and Ü. Ayata, "200 derecede ısıl işlem görmüş amaouk (Detarium macrocarpum) odununda bazı yüzey özelliklerinin ve shore D sertlik değerlerinin incelenmesi," in 3. Uluslararası Karadeniz Modern Bilimsel Araştırmalar Kongresi, Samsun, 2023, pp. 670–678.
[27]. Türk, M., Ayata, Ü., (2021), Türkiye'de yetişen bazı ağaç türlerine ait odunlarda shore D sertlik değerleri üzerine ısıl işlemin etkisi, Mobilya ve Ahşap Malzeme Araştırmaları Dergisi, 4(2), 166-173, DOI: 10.33725/mamad.1005127.
[28]. Hillis, W.E., (1984), High temperature and chemical effects on wood stability, Wood Science and Technology, 18(4), 281-293. DOI: 10.1007/BF00353364.